Vegetation Restoration in the Chihuahuan and Sonoran Deserts of North America

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An appendix to this publication, containing detailed data on the classification of successful and unsuccessful species seeded in the past 92 years, is available from USDA, ARS, Arid Land Ecosystems Improvement, 2000 East Allen Road, Tucson, Ariz. 85719.

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ABSTRACT

Attempts to restore depleted rangelands in the Chihuahuan and Sonoran Deserts of the southwestern United States and northern Mexico have been ongoing since 1890. More than 300 forb, grass, and shrub species and accessions have been seeded on 40 mechanically prepared seedbeds at 400 planting sites. Eighty-three species and eight seedbed preparations have been recommended, but a successful planting could be expected in only 1 of 10 years.

A review of the available information indicates that: (1) 11 plant species are adapted for range reseeding and a successful planting can be expected in 1 of 2 or 3 years, but each species is adapted to a relatively small geographic area; (2) no single seedbed treatment is superior to others; and (3) new personnel involved in range reseeding frequently repeat earlier experiments because an adequate literature base is unavailable.

KEYWORDS: Range reseeding, history, southwestern rangelands, range research, southeastern Arizona, southern New Mexico, west Texas, northern Mexico, Chihuahuan Desert, Sonoran Desert, semidesert grasslands.

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VEGETATION RESTORATION IN THE CHIHUAHUAN AND SONORAN DESERTS OF NORTH AMERICA

By Jerry R. Cox, Howard L. Morton, Thomas N. Johnsen, Jr., Gilbert L. Jordan, S. Clark Martin, and Louis C. Fierro[1]

INTRODUCTION

Efforts to improve rangelands in southeastern Arizona, southern New Mexico, and west Texas have a long history. Documented research has been carried out for over 90 years by various private and governmental agencies; however, environmentalists, ranchers, research scientists, and land management administrators agree that information for improving the productivity of western rangelands is often unusable or unavailable (Day *1979*).[2]

We reviewed all available popular and scientific information dealing with rangeland restoration in the desert southwestern United States and northern Mexico. Our objectives were to: (1) present information in chronological order and show the development of range problems and research efforts, (2) indicate the contribution of research results, and (3) identify research characteristics and direction needed to produce fundamental and widely applicable results.

Many rangeland restoration studies are generally unknown because researchers have not published results in readily obtainable form. Consequently, new research thrusts must lay new groundwork that might have been laid by preceding generations.

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 25.

DESCRIPTION OF THE STUDY AREA[3]

The semidesert grassland occurs within the Chihuahuan and Sonoran deserts of North America (fig. 1). The study areas are located in southeastern Arizona, southern New Mexico, southwest Texas, and northern Mexico (the States of Chihuahua, Coahuila, Sonora, and the northern portions of Durango and Zacatecas). Topography is primarily broad alluvial plains, fans, and river bottoms with intermittent mountains. The Soil Conservation Service (SCS) classifies the area as Chihuahuan or Sonoran (upper and lower) Desert Shrub. The elevation ranges from 0 to 1850 m, the average annual temperature ranges from 10° to 24°C, and the number of frost-free days varies from 160 to 360. Precipitation ranges from 5 to 50 cm. Rainfall distribution is 60 to 40 percent for the Chihuahuan and 40 to 60 percent for the Sonoran in summer and winter. Soils are usually Aridisols or Entisols but may approach Alfisols or Mollisols at specific sites.

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[3]These are general descriptions for large areas; significant deviations do occur.

Figure 1.--The Chihuahuan and Sonoran Deserts, desert grasslands, and transition.

The vegetation is characterized by perennial, drought resistant woody and succulent species, adapted to conserve water in drought periods; perennial grasses; and various types of annuals. Typical species are creosotebush (*Larrea tridentata* (DC.) Cov.), tarbush (*Flourensia cernua* DC.), bursage (*Ambrosia* spp.), paloverde (*Cercidium* spp.), cactus (*Opuntia* spp.), mesquite (*Prosopis* spp.), catclaw (*Acacia greggii* A. Gray), whitethorn (*Acacia constricta* Benth.), saltbush (*Atriplex* spp.), and yucca (*Yucca* spp.).

Perennial grasses are gramas (*Bouteloua* spp.), bush muhly (*Muhlenbergia porteri* Scribn.), cane bluestem (*Bothriochloa barbinodis* (Lag.) Herter), cottontop (*Digitaria californica* Henr.), tridens (*Tridens* spp.), tobosa (*Hilaria mutica* (Buckl.) Benth.), dropseeds (*Sporobolus* spp.), and threeawns (*Aristida* spp.).

Annuals are indianwheat (*Plantago* spp.), primrose (*Oenothera* spp.,) mustards (Cruciferae), legumes (Leguminosae), borage (Boraginaceae), composites (Compositae), threeawns, and gramas.

METHODS

To standardize our data, we interviewed individuals who directly or indirectly had knowledge of methods and procedures used in the studies. We visited over 40 planting sites in the southwestern United States and northern Mexico to gain familiarity with conditions needed to interpret information from nonvisited sites. Unfortunately, differences in individual techniques forced us to use only two rating classes: success or failure.

When quantitative data were available, a stand with at least one plant per square meter was considered successful. A rating could not be made in some instances, and such information was considered as a failure unless the researcher rated the stand two or more times over several years. Sometimes a species was initially successful, but failed within 1 to 8 years.

Inconsistencies among methods, individuals, and years made a statistical analysis of the data meaningless. Moreover, much of the reviewed information is incomplete or unconclusive. Our interpretations are based on summaries showing trends.

RESULTS

The results have been arbitrarily divided for ease of reading into sections: (1) Development of the Problem (1521-1900), (2) Recognition of the Problem and Early Work (1900-30), (3) Organized Research (1930-45), and (4) Current Reseeding Research (1945-80).

Development of the Problem (1521-1900)

The first European beef animals to enter the New World were introduced by ship and unloaded in Mexico during 1521. Cattle and sheep were introduced into

the semidesert grasslands as the Spanish began exploring the northern frontier. Livestock distribution continued to expand as Father Kino established missions and small herds throughout Chihuahua, Sonora, southeastern Arizona, and southwestern New Mexico (1697-1740). Between 1770 and 1827, the Spanish cattlemen were frequently forced from the frontier by Indians, malaria, and drought (Bahre *1977*). Well over 500,000 head freely roamed the frontier (Wagoner *1952*), and many were killed for food and hides between 1830 and 1840.

American botanists and military personnel (Bartlett *1854*; Hinton *1890*; Barnes *1936*) traveling in the valley bottoms and foothills of the semidesert grasslands noted lush sacaton (*Sporobolus airoides* (Torr.) Torr. and *S. wrightii* Mung ex Scribn.) in the bottoms with relatively brush-free upland areas (Humphrey *1958*) dominated by tobosa and grama grasses (fig. 2). Brushy species, such as mesquite, catclaw, whitehorn, creosotebush, and tarbush, were present but limited in numbers (Barnes *1936*).

After American exploration and the control of most Indian tribes, American and Mexican cattlemen freely grazed the lush grasslands. Railroad expansion, following the American Civil War and the revolutions in Mexico, provided rapid transportation and movement of agricultural and mining products (Hastings and Turner *1965*). As population increased so did the demand for meat and vegetables. Cattle were driven or shipped from eastern Texas and Mexico into the southwestern United States and north central Mexican river valleys. Fertile lowlands were plowed and the rivers rechanneled to provide irrigation for crops. Most water sources dried up by 1893, resulting in the death of 50 to 75 percent of the livestock population (fig. 3). The drought was over by 1895, but the combined effects of overgrazing, drought, and flooding (fig. 4) had resulted in accelerated sheet and gully erosion (Jordan and Maynard *1970a*) and loss of the shallow water tables in valley bottoms (Bryan *1925*).

Recognition of the Problem and Early Work (1900-30)

Griffith (*1901*) reviewed the deterioration of rangelands in 1899 and published statements of area ranchers in southern Arizona. H. C. Hooker, owner of the Sierra Bonita Ranch, described the destructive events: "In 1870 there were large beds of sacaton and grama grasses and the San Pedro River ran shallow with the banks covered with grass, shrubs and cottonwood trees (fig. 5). In 1900 the river bed had dropped 20 feet and the vegetation had been removed by grazing, farming and flooding." Commenting on livestock density, Hooker stated: "There were fully 50,000 head of stock at the upper end of the Sulpher Spring Valley in 1890. In 1900 there were not more than one-half that number, and they are doing poorly." C. H. Bayless, of Oracle, Ariz., stated: "Beaver dams checked water flow in 1885, but the trappers exterminated the population and within 5 years the channel was from 3 to 20 feet deep." Bayless grazed 40,000 cattle in 1888, but in 1901 there was insufficient forage for 3,000. Other statements (Bartlett *1854*; Hinton *1890*; Barnes *1936*) indicated similar vegetation changes throughout the semidesert grasslands.

Humphrey (*1958*) estimated 1.5 million head were on southeastern Arizona ranges in 1893. At least 4 million head of livestock probably grazed in

Figure 2.--The Santa Rita Experimental Range near the Proctor homestead: *Top*, In 1902 (J. J. Thornber, U.S. Forest Service). *Bottom*, The same area in 1980. The grasslands have been replaced by mesquite, burroweed, and cacti.

Figure 3.--Cattle bones at Vail Station in 1902 (J. J. Thornber, U.S. Forest Service).

southwest Texas, southern Arizona, and New Mexico between 1880 and 1893. Similar numbers probably grazed Mexican rangelands.

After documenting range deterioration, the USDA, Division of Agrostology, and State Experiment Stations at Tucson and Las Cruces began cooperative research in the 1890's to determine the feasibility of reseeding native and introduced forage species to restore rangelands (fig. 6). A variety of species were planted under irrigated and dryland conditions. Generally, successful plantings were limited to irrigated plots.

Thornber (*1905*, *1906*, *1907*, *1908*, *1910*), Griffith (*1904*, *1907*, *1913*), Blount (*1892*), and Keffer (*1899*) began grass, forb, and shrub species adapation trials. The results of duplicate plots on irrigated and nonirrigated areas indicated that teff (*Eragrostis abyssinica* (Jacq.) Link.) was adapted for upland range sites; however, subsequent trials revealed this species would not persist without supplemental watering. Thornber (*1911*) concluded that cactus was important for sustaining livestock during drought. Spined and spineless cacti were planted in ungrazed and grazed pastures and survival evaluated, and only cactus with spines survived.

Figure 4.--*Top*, Warner Lake near Tucson before 1895 (Arizona Historical Society). *Bottom*, Warner Lake was washed out in the 1890's. Today, the 22d Street interchange crosses the Santa Cruz River at Warner Lake.

Figure 5.--Type of vegetation originally found along the San Pedro and Santa Cruz Rivers before 1895. The photograph was taken at the Empire Ranch in 1980.

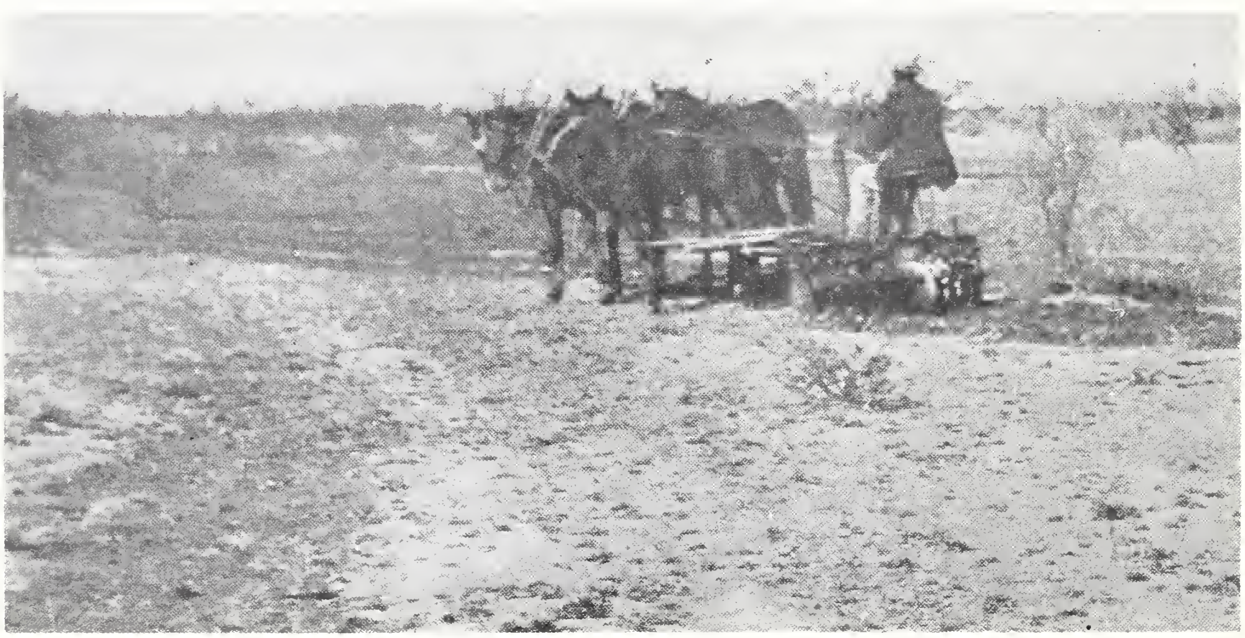

Figure 6.--Mechanical seedbed preparation in 1902 (J. J. Thornber, U.S. Forest Service).

The early reseeding failures resulted in a second line of research emphasizing the improvement of rangelands with grazing management (Jardine and Hurtt *1917*). A 22-year grazing experiment on the Jornada Experimental Range showed that the amount of forage produced in the best years was four times that in the poorest. Both livestock and range benefited when stocking rates were set for the average years (Upson and McGinnies *1939*).

Early revegetation investigators were either looking for a "miracle plant" that could produce an abundance of good quality forage with limited precipitation or trying to develop a variety that would surpass native species through plant breeding (Upson and McGinnies *1939*). Such a "painless cure-all" was improbable (Thornber *1910*; Wooton *1916*; Jardine and Anderson *1919*; Sampson and Malmsten *1926*; Chapline *1937*), and future reseeding studies were designed to determine ecological, physiological, and agronomic requiremets of plants.

Wilson (*1928*, *1931*) conducted laboratory and field studies to determine the ecological and physiological requirements of fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Wilson (*1936*) determined the proper use of seeded johnsongrass (*Sorghum halapense* (L.) Pers.) and its use for slowing runoff in stream channels. Griffith (*1907*) seeded johnsongrass in 1901, but the seedlings died. Johnsongrass seeding was adopted by the SCS and used extensively in southwest[4] and central Texas (Bell *1973*).

Scientific range management in the desert southwest began in the 1930's, but early agronomists and botanists, such as J. Bentley, A. E. Blount, R. H. Forbes, D. Griffith, C. A. Keffer, A. D. Smith, P. S. Standley, J. J. Thornber, C. P. Wilson, and E. D. Wooton, contributed to the development of the art of southwestern range management (Beetle *1954*; Costello *1964*). These individuals were keen observers and collectively identified the problems associated with overgrazing. They began an evolutionary process (Beetle *1954*) that resulted in (1) the Taylor Grazing Act of 1934 and (2) the discipline of range management.

Organized Research (1930-45)

The passage of the National Industrial Recovery Act (NIRA), Work Progress Administration (WPA), and the Civilian Conservation Corps (CCC) in the 1930's made funds available to hire scientists to conduct research in reseeding, ecology, and the development of range methodology (Dana *1956*; Price *1976*). Scientific range management in the desert southwest began in 1932 with a Junior Range Examination at the Tucson Post Office. The test was later given at other locations and was equally divided into subjects of botany and animal husbandry.

The initial results from reseeding trials in 1934 through 1936 were promising (Barnes et al *1958*) due to above average rainfall, but rainfall was below average in 1937 through 1939 and plantings failed (Anderson and Swanson *1949*). Glendening (*1939a*, *1939b*, *1942*) and Hendricks (*1939*) used surface

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[4]Data provided by D. Butler, SCS, Fort Stockton, Tex.; S. T. Holtz, SCS, Van Horn, Tex.; and K. McCain, SCS, Dell City, Tex.

mulches to reduce evaporation. Their results showed soil moisture was greater under straw and gauze mulches than beneath bare ground. Mulching increased grass germination from 4 to 20 times. The increased germination with mulches suggested surface moisture conservation was an important component for establishing forage grasses.

On alkaline sites, mulches did not enhance germination or seedling establishment. Glendening (*1937*), Cassady (*1938*), and Cassady and Glendening (*1940*) excavated and transplanted native perennial grasses in summer and winter. All transplants were watered, and summer transplants were covered with wet burlap to reduce evaporation and transpiration. Hendricks (*1936*) grew black grama (*Bouteloua eriopoda* (Torr.) Torr.) and vine mesquite (*Panicum obtusum* H. B. K.) from seed and then transplanted. Generally, transplanting was unsuccessful. Transplants were carefully planted or excavated, watered, and replanted, but the chemical and physical site characteristics were extreme and survival was less than 5 percent (U.S.F.S., unpublished data).

Parker and McGinnies (*1940*) assumed that individual species had different environmental and biological requirements. They listed 30 potentially adapted species and provided information on when, where, and how to plant each. Generally, grasses were to be planted prior to summer rains, and shrubs, such as fourwing saltbush, in early fall (fig. 7).

Figure 7.--A successful seeding of fourwing saltbush by J. O. Bridges at New Mexico State University College Ranch in the Fall of 1936 (Ken Parker, U.S. Forest Service).

Native species failed to persist at southwestern revegetation sites (Reynolds *1949*; Martin *1957*) and a variety of cool and warm season forbs, grasses, and shrubs were introduced in the 1930's and early 1940's. Species were screened for drought tolerance (Hamilton *1964*, *1969*) at Soil Conservation Plant Materials Centers and then released for rangeland planting. Bridges (*1941*) seeded 174 native and introduced species on sandy loam soils near Las Cruces. Rothrock grama (*Bouteloua rothrockii* Vasey), Boer lovegrass (*Eragrostis chloromelas* Steud.), Lehmann lovegrass (*E. lehmanniana* Nees), and fourwing saltbush were established at the site (fig. 8). Bridges (*1947*) conducted germination tests on the remaining species and determined that seedling survival was dependent on precipitation and depth of seeding rather than seed viability.

Bridges (*1947*) determined the importance of seedbed preparation and seedling depth. Eight mechanical seedbeds were hand seeded with 118 species of grasses and shrubs in summer and winter on sandy loam and clay loam soils in Arizona and New Mexico. Plant establishment was better with combinations of contour furrowing and harrowing when seed were sown before summer rains. Laboratory studies showed the importance of seeding grasses and shrubs near the soil surface.

Serious national and worldwide problems affected range research between 1930 and 1945. In 1933, a major drought and a worldwide economic depression

Figure 8.--Photograph of Lehmann lovegrass at the Soil Conservation Service Cooperative, University of Arizona, and U.S. Forest Service reseeding site on the Larrimore Ranch, Santa Cruz Co., Ariz., in 1942 (Ken Parker, U.S. Forest Service).

seriously affected fiber and meat production. To stabilize the national economy, Congress enacted legislation to create jobs and restore food production. Funds and labor were made available to USDA for range management research; however, funds and labor were rechanneled to the military as the country entered the 1938-40 prewar period.

Many scientists were drafted during World War II, which further disrupted range seeding studies. The remaining scientists had to keep up with too many studies, and time often limited field replications. The situation was confounded by variations in data collection methods. Each individual or agency had different methods for acquiring data, some were quantitative, some were qualitative, and others were combinations. Thus, results were not comparable among different study sites.

The situation was discontinuous, but there were good studies. However, the results often stressed failures, which were not published in scientific journals; thus, reseeding information was disseminated during field tours as typed or mimeographed handouts. Handouts were limited in distribution and were seldom preserved for future use. Researchers and administrators recognized the problems and tried to correct them in the 1950's by developing agency publications and new professional groups such as the Society for Range Management.

Current Reseeding Research (1945-80)

Methods for evaluating establishment and persistence in combination with grazing began to change after World War II (Reynolds et al. *1949*). Field studies were designed to (1) determine plant adaptability at different range sites, (2) develop and test methods for economically establishing species, (3) appraise indicators to judge site reseeding potential, and (4) evaluate the grazing value of reseeded plants. More than 200 grasses, forbs, and shrubs were seeded in rabbit and livestock exclosures in Arizona and New Mexico (Judd and Judd *1976*). Successful species were then seeded in replicated lots. Selections from these were planted on 12- to 49-ha plots for grazing potential evaluation (Lavin 1944; Bridges *1947*; Reynolds *1948*; Springfield and Housley *1952*). Unfortunately, because of livestock preference, reseeded sites within large pastures were often overgrazed even under light to moderate grazing. Then came the recognition that species, especially those reseeded, might require specific management considerations (Reynolds *1959*; Reynolds and Martin *1968*; Springfield *1956*, *1965*).

The Forest Service[5] ranked southwestern reseeding trials by geographic land area, elevation, and precipitation to determine areas where success might be maximized. The geographic priority list (from high to low) was:

1. central Arizona and northern New Mexico
2. northern Arizona and western New Mexico
3. eastern New Mexico and the Texas Panhandle

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[5]U.S. Forest Service Internal Reports on Range Reseeding. K. W. Parker and D. M. Thompson. 1945. [Unpublished.]

4. southeastern Arizona, southern New Mexico, and west Texas
5. southwestern Arizona
6. Arizona Strip and northwestern New Mexico

Thus, USFS vegetation efforts were conducted at higher elevations within forests and mountain meadows. The SCS and State universities continued and expanded revegetation studies at lower elevations in the pinyon-juniper woodland, semidesert grasslands, and desert shrubland.

In 1953, all reseeding research, with the exception of browse species, was transferred to the newly formed ARS. The USFS continued reseeding research at high priority geographic areas as cooperative programs with the SCS and universities in Arizona, New Mexico, and Texas. By the mid-1950's, ARS, SCS, and southwestern university personnel were actively engaged in reseeding trials in low priority areas. These efforts have resulted in (1) the development of machinery for seedbed preparation, (2) the selection of species and cultivars adapted for rangeland planting, and (3) mechanical and chemical methods for limiting competition of weedy plants.

A variety of mechanical devices (figs. 9 and 10) has been developed and used to prepare a seedbed and construct a favorable microclimate for germination and seedling growth (Branson et al. *1966*). In some instances, seedbed species failed

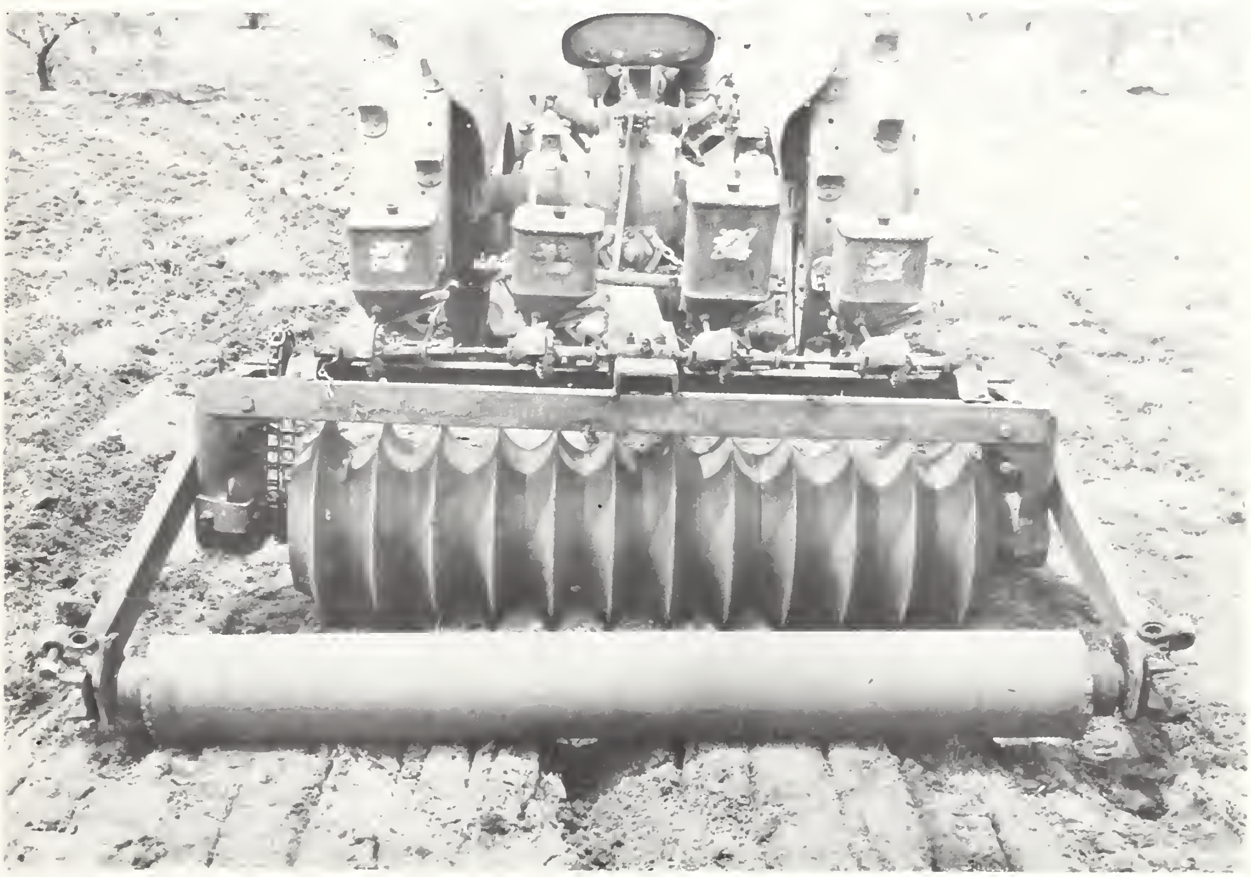

Figure 9.--Planet Jr. seedboxes, cultipacker, and press-wheel roller pulled by a tractor with steel rims in 1949 (Fred Lavin, U.S. Forest Service).

Figure 10.--Eccentric disk followed by a two-bank cultipacker in 1954 (H. G. Reynolds, U.S. Forest Service).

to germinate or establish; therefore, physical soil parameters were used to evaluate methods of seedbed preparation (Dortignac *1954*). Pitting and ripping were shown to reduce runoff and increase infiltration (Anderson and Swanson *1949*; Barnes et al. *1958*; Brown and Everson *1952*). Hickey and Dortignac (*1963*) compared pitting and ripping on three different soil types. Runoff averaged 4 percent for ripping and 15 percent for pitting after 12 months, but increased to 12 percent and 24 percent, respectively, after 3 years. Pitting increased moisture in clayey soils, but increased moisture does not always enhance seedling establishment.

Frost and Hamilton (*1964a*, *1964b*) used three sizes of pits on clayey and sandy loams at 990 m elevation. All pits were hand seeded with five warm-season perennial grasses. Buffelgrass (*Cenchrus ciliaris* L.) and blue panicgrass (*Panicum antidotale* Ritz.) were abundant in all pit sizes after one year. Recent evaluations indicated yellow bluestem (*Bothriochloa ischaemum* (L.) Keng var. *ischaemum*) has persisted in small pits on sandy clay loam soils (L. P. Hamilton, personal communication). Slayback and Cable (*1970*) and Slayback and Renny (*1972*) evaluated buffelgrass emergence and production in three sizes of pits at 1230 m. Buffelgrass production was least in small pits and greatest in large pits. Plant production in the largest pits was not significantly different from intermediate pits, which required less time and energy to construct.

Pitting recommendations vary for soil types and geographical areas. Pitting is not recommended for sandy and extremely rocky soils or on steep slopes (Anderson et al. *1953*, *1957*; Hamilton *1958*). Pitting is more effective on medium to heavy textured soils where water ponding increases infiltration (Caird and McCorkle *1946*; Valentine *1947*; Hubbell and Gardner *1950*; Barnes et al. *1958*). Pit size and seed size may effect germination and initial establishment.

Major climatic differences between the Chihuahuan and Sonoran deserts are easily recognized; while minor climatic variations within each desert are unapparent without precise measurements of elevation, precipitation, and soils. Thus, even when seedbed methods and seeded species are the same, results vary from site to site and year to year. Jordan (*1968*, *1969*, *1970*, *1971*) used chaining, diskplowing, and root plowing to reduce brush competition at three southeastern Arizona sites receiving 20 to 25 cm annual precipitation. Each treatment was pitted and sown to Lehmann lovegrass. The planting sites are strategically located in a transition zone between the Chihuahuan and Sonoran Deserts. Jordan (*1968*) found that Lehmann lovegrass would initially establish at all sites, but density and production rapidly declined without root plowing at 30- to 45-cm depths. Root plowing plus pitting increased soil moisture, wetting depth, and Lehmann lovegrass production (Jordan and Maynard *1970b*).

Jordan (*1969*, *1970*, *1971*) seeded a variety of perennial grasses and recently developed lovegrass cultivars (Wright and Brauen *1971*; Wright and Dobrenz *1973*) at the same three sites (fig. 11). Adapted species were: Lehmann lovegrass (A-68, L-28, L-38), Boer lovegrass (A-84, Catalina), blue panicgrass (A-130), and Cochise lovegrass (*Eragrostis lehmanniana* Nees X *Eragrostic trichophera* Coss and Dur.) (Rockenbaugh *1979*) at elevations above 1000 m in southeastern Arizona.

Figure 11.--This area, in the San Simon Valley, was root plowed, pitted, and sown to Cochise lovegrass by G. L. Jordan in 1971. The photograph was taken in 1980.

blue panicgrass has persisted for 10 years at sites below 980 m, while most lovegrass (A-68) died.

Lavin (*1958*, *1962*) conducted seeding studies, similar to those of Jordan's, at 1000 to 1300 m in southcentral Arizona. Mesquite were root plowed and seedbed methods were compared. Precipitation was 35 to 40 cm, and plant establishment was unrelated to pitting treatments. Combinations of soil firming and rock mulches increased the stand densities of Lehmann and Wilman lovegrass (*Eragrostis superba* Peyr.). However, stand densities declined as populations of burroweed (*Haplopappus tenuisectus* (Greene) Blake ex Benson) and snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. + Rusby) increased.

Root plowing, pitting, seeding, soil firming, and litter spreading were combined into one operation, and the method was tested on clayey, sandy, loamy, and gravelly sandy loam soils at 23 creosotebush sites in southern New Mexico (Herbel *1972*). Sites were seeded with perennial grasses and fourwing saltbush (Herbel et al. *1973*). Lehmann (A-68) and Boer (A-84) lovegrass, black and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), blue panicgrass (A-130), and fourwing saltbush were promising in wet summers on loamy upland soils. On moist alluvial soils, yellow bluestem and alkali sacaton were promising.

Downs (*1961*) evaluated SCS range seedings conducted between 1939 and 1955 in southern New Mexico. Sixty-eight accessions of perennial grasses and shrubs were seeded at 30 locations, where elevation ranged from 960 to 1212 m. The most persistent species were galleta grass (*Hilaria jamesii* (Torr.) Benth.) and tobosa grass. Lehmann lovegrass persisted for 15 years at elevations below 1200 m and 4 years at elevations above 1500 m.

The SCS began accession trials in southeastern and southwestern New Mexico in 1966 (Niner *1967*; Hassell *1979*). Blue grama (NM-118), Lehmann lovegrass (A-68), and Boer lovegrass (Catalina) were easily established, but both lovegrasses died in cold years (Anderson *1978*).

Problems associated with range seeding trials between 1900 and 1945 still exist today. Methods are nonstandard, and scientists continue to underestimate time demands. As a result, comparisons among sites, seedbed methods, and seeded species are impossible because: (1) onsite weather data were not collected; (2) new seedbed methods were not compared with existing standards; (3) trials were unreplicated in time and space; (4) data collections were subjective, differing among individuals and agencies; and (5) common seed sources were often identified as separate genetic introductions (that is, Lehmann lovegrass accessions A-68, A-14107, A-14328, NM-317, and MN-13317 are from a common introduction).

The situation becomes more confusing when positive results, obtained at atypical sites or in atypical years, were extrapolated and recommended for use over large areas. For example, Lehmann lovegrass is recommended for use in southern New Mexico, and Wilman lovegrass in southeastern Arizona (Slayback *1972*; Anderson *1978*). At upland sites, both will germinate in wet summers and persist in mild, wet winters (Briggs and Hassell *1973*; Holzworth et al. *1978*; Raynor *1972*); however, neither species will survive in dry, cold winters or in more arid sites in either the Chihuahuan or Sonoran Deserts.

A range research and extension program was initiated at La Campana Experimental Ranch, Chihuahua, Mexico, in 1958. Species adaptation trials are currently conducted at 30 locations in the Mexican States of Chihuahua, Coahuila, and Sonora.[6] Seedbed preparation and planting methods are similar to those in the United States, but adaptation trials are usually replicated in time and space, and data collection consists of quantitative parameters per unit area. Seeding trials in Mexico have provided new information on adapted species and methods of seedbed preparation.

More perennial warm season grasses have been established from seed on the central Chihuahuan Plateau than any other locations in Mexico. Elevation is 1385 to 1850 m and precipitation is 35 to 50 cm a year. Lehmann lovegrass (A-68), Boer lovegrass (A-84), Wilman lovegrass, Kleingrass-75 (*Panicum coloratum* L.), johnsongrass, sorghum almum (*Sorghum* X *almum* Parodi), sideoats grama, and green sprangletop (*Leptochloa dubia* (H.B.K.) Nees) germinate and persist when moderately used in a rest-rotation grazing system (Echavarria *1973*; Jabalera et al. *1976*; Sanchez *1976*; Jabalera and Fierro *1977*; Fierro et al. *1979*; Ibarra and Gomez *1979*). In dry years, contour furrows increase stand density, but in average or wet years stand density is similar for all seedbed treatments (Fierro and Gomez *1977*).

Economic conditions in southwestern Coahuila and northern Zacatecas limit the use of conventional range seeding techniques (Gloria et al. *1978*). Interior Chihuahua lowland elevations are 310 to 615 m, and average annual precipitation varies between 15 and 20 cm. Winters are warm and dry, summers extremely hot (Ibarra et al. *1979*). Perennial grass adaptation trials are conducted in handmade microwatersheds with 1:1, 1:2, and 1:3 runon to runoff ratios and shrub trials in 0.5 to 2.0 m circular pits (Ancira *1980*).

Perennial grasses may germinate and persist in 1:2 runon to runoff microwatersheds (Orozco et al. *1977*; Nava et al. *1977*). Fourwing saltbush growth is maximized in 3 m pits (Garza et al. *1977*; Ibarra et al. *1979*).

The Sonoran Coastal areas around Hermosillo, Mexico, can be converted to productive rangelands after brush removal and seeding. Precipitation is equally divided between summer and winter, the annual average is 30 cm. Winters are warm and mild, summers are hot and moist. Relative humidity in summer averages 65 to 80 percent. The dual growing season, high humidity, and consecutive treatments of dozing, ripping, disking, seeding buffelgrass, and chaining optimize forage production. This series of treatments has been consistently successful for 23 years. Forage production on treated sites averages 1500 to 3000 kg/ha (Cota and Johnson *1975*; Cota et al. *1978*; Velasquez et al. *1978*).

Seeded species can be established in the Sonoran Interior Lowland, but seedlings must persist through droughty spring and fall periods (Cable *1976*). Winters are moist and warm, summers are hot and dry. Yellow bluestem (Common) appears to be adapted to the area but stands rapidly decline at higher elevations. At lower elevations, where average annual temperature exceeds 20°C and

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[6]Data provided by L. C. Fierro, Chihuahua, Mexico; V. DelSid, Sonora, Mexico; and R. Vasquez, J. G. Medina, and H. M. Garza, Coahuila, Mexico.

precipitation exceeds 30 cm, yellow bluestem germinates and rapidly spreads in fenced plots.

Seeding failures in semidesert grasslands are correlated with soil moisture depletion (Stoddard et al. *1975*). Soil moisture depletion is due to evaporation or transpiration by annual forbs (Klingman and Ashton *1975*) perennial shrubs (Tschirley and Martin 1961; Schmutz *1967*), and inadequate amounts and distribution of precipitation (Jordan and Maynard *1970b*). Competition must be controlled or reduced before and after planting to establish and maintain seeded populations. Control may be accomplished by either mechanical or chemical methods. Mechanical methods are costly, disturb the soil, and often results in new weed invasions or short term brush control (Tromble *1974*; Simanton et al. *1977*).

Research has shown that herbicides can reduce plant competition with minimal site disturbance. General weed control herbicides, like paraquat[7] (Young et al. *1971*) and glyphosate[8] (Baur et al. *1977*), effectively control competition during germination and seedling growth, but applications must be precisely timed. Experiments indicate pelleted or granular herbicides, like tebuthiuron,[9] karbutilate,[10] and picloram,[11] are absorbed from the soil by roots, remain active in the soil for extended periods, and are less dependent on time of application.

Evans et al. (*1967*, *1969*, *1970*) have shown the importance of weed control on the establishment of perennial grass seedlings in the Great Basin; however, reseeding may not be necessary if a remnant native population exists (Morton et al. *1976*, *1978*). Shrubby competition was completely removed with pelleted herbicides in a mixed brush community at 954 m on the Santa Rita Experimental Range in 1979. Perennial native forage production was 250 kg/ha before treatment, 800 kg/ha after 4 months and 5 cm of precipitation, 2500 kg/ha after 16 months and 17 cm of precipitation, and 3200 kg/ha after 28 months and 38 cm of precipitation (fig. 12). Not all range sites have this production potential, but most sites will show substantial increases in native forage production if (1) plant competition is reduced, (2) dead standing litter remains in place after treatment, and (3) grazing is excluded or reduced.

REVIEW OF PAST WORK

Rangeland seedings conducted in the past 92 years include more than 300 forb, grass, and shrub species; 40 mechanically prepared seedbeds; and approximately 400 planting sites in the southwestern United States and northern Mexico. Eighty-three species are or have been classified as successful and are recommended for rangeland use. Unfortunately, some recommendations are based on pre-

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[7]1,1'-dimethyl-4,4'-bipyridinium ion.
[8]*N*-(phosphonomethyl)glycine.
[9]*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N*'-dimethylurea.
[10]*tert*-butylcarbamic acid ester with 3(*m*-hydroxyphenyl)-1,1-dimethylurea.
[11]4-amino-3,5,6-trichloropicolinic acid.

Figure 12.--*Top*, A typical mixed brush Sonoran site in June 1979. *Bottom*, The same site after complete brush control and fencing in September 1980. The dominant grass is Arizona cottontop.

mature results, infrequent observations, poorly conducted experiments, and data collected at atypical sites or in atypical years. In spite of these inconsistencies, a considerable amount of useful information does exist. The following general conclusions were gleaned from the total data base:

1. Introduced perennial grasses have been most successful, whereas annual and perennial forbs, native grasses, and shrubs usually failed.

2. Establishment and stand persistence is determined by effective moisture use, which is influenced by competition and time of planting.

3. Seeded species are most easily established on coarse-textured soils.

4. Stand establishment is not directly related to any method of seedbed preparation.

5. Small seeds may be aerially broadcasted on freshly prepared seedbeds and covered by natural processes (such as wind and water), but large seed or pelleted seed must be covered by soil using mechanical treatments (Kimball *1952*; Hull et al. *1963*).

We are unable to make specific recommendations that will apply to the whole semidesert grassland or to individual deserts; however, when the total area is divided into eight reference zones we could more clearly approximate adapted species as well as general plant requirements. The reference zones are based on elevation, precipitation, frost-free days, growing season length, and season of effective precipitation (table 1). The data are general, cover large land areas, and need refinement for individual planting sites. Under other conditions, these species (here considered to be successes) were considered to be failures. Nevertheless, this information does provide insight for selecting species that have been tested and are known to persist. Geographic borders for reference zones are:

I. Chihuahuan Interior Lowland: southern Coahuila, southern Nuevo Leon, northern San Luis Potosi, and northern Zacatecas.

II. Chihuahuan Interior Plateau: northern Durango, southern and central Chihuahua, western Coahuila, and the Trans-Pecos area of southwest Texas.

III. Chihuahuan Northeast Upland: southeast New Mexico and the southern Rio Grande Valley in New Mexico and west Texas.

IV. Chihuahuan Northwest Upland: southwest New Mexico and north central Chihuahua.

V. Transition of Chihuahuan Northeast Upland and Sonoran Interior Upland: Douglas, Ariz., north to Bowie, Ariz., and east to the New Mexico border.

VI. Sonoran Interior Upland: Douglas, Ariz., and west to Nogales, Ariz.

VII. Sonoran Interior Lowland: northeast Sonora and south central Arizona.

VIII. Sonoran Coastal: southwest Sonora and northwest Sinaloa.

Table 1.--*Classification of adapted species based on reference zones within the Chihuahuan and Sonoran Deserts*

Desert	Reference zone	Elevation	Precipitation	Frost-free days	Annual growth days	Season of effective precipitation	Adapted species
		Meters	*Centimeters*				
Chihuahuan	Interior Lowland	310-615	15-25	320-340	20-35	Summer	Fourwing saltbrush.
	Interior Plateau	1385-1850	35-50	220-240	100-120	Summer	Blue panic--lower elevations. *Sideoats grama--higher elevations. *Lehmann lovegrass (A-64)--all elevations. *Boer lovegrass (A-84)--middle and higher elevations. *Wilman lovegrass--higher elevations. *Green sprangletop--higher elevations. *Kleingrass (75)--middle and higher elevations. *Johnsongrass--all elevations. *Sorghum almum--all elevations.
	Northeast Upland	920-1120	25-35	260-270	50-60	Summer	Sideoats grama (Vaughn, NM-28)--higher elevations.
	Northwest Upland	1100-1385	30-35	250-260	40-50	Summer	Sideoats grama (Vaughn)--higher elevations. Yellow bluestem (Ganada)--lower elevations.
Transition	Northwest Upland Chihuahuan	1100-1230	30-40	270-290	60-75	Summer and winter	*Lehmann lovegrass (A-68)--all elevations. *Boer lovegrass (A-84, Catalina)--all elevations. *Cochise lovegrass (A-15608)--all elevations. *Blue panic (A-130 and SEA-SDT)--middle and lower elevations.

Table 1.--*Classification of adapted species based on reference zones within the Chihuahuan and Sonoran Deserts*--Continued

Desert	Reference zone	Elevation	Precipitation	Frost-free days	Annual growth days	Season of effective precipitation	Adapted species
		Meters	*Centimeters*				
							Kleingrass (75)--middle and lower elevations. Weeping lovegrass (A-67)--higher elevations.
Sonoran	Interior Upland	920-1385	30-40	280-300	70-85	Summer and winter	Sideoats grama--higher elevations. *Lehmann lovegrass (A-68)--all elevations. *Boer lovegrass (A-84, Catalina)--middle elevations. *Cochise lovegrass (P-15068)--middle elevations. Blue panic (A-130, SEA-SDT)--middle elevations. Kleingrass (75)--middle elevations. Green sprangletop--higher elevations. Yellow bluestem (A-14207)--middle elevations.
	Interior Lowland	460-920	25-30	338-350	50-70	Winter	*Lehmann lovegrass (A-68)--higher elevations. Cochise lovegrass (P-15608)--higher elevations. Yellow bluestem (A-14207)--higher elevations. Buffelgrass (Common)--lower elevations.
	Coastal	0-460	30	364	100-120	Winter and summer	*Buffelgrass (Common).

*Consistently successful throughout the Reference Zone.

No species is adapted to all reference zones, but at specific locations within all reference zones one or more species can be established in 1 out of 4 years (75-percent failure). In five reference zones, one or more species can be established in 1 out of 2 years (50-percent failure). The diversity of seeded and established species from most diverse to least diverse is: (1) Chihuahuan Interior Plateau, (2) Transition, (3) Sonoran Interior Upland, (4) Sonoran Interior Lowland, (5) Sonoran Coastal, (6) Chihuahuan Interior Lowland, (7) Northeast Upland, and (8) Northwest Upland.

Fourteen species can be regularly established and 10 consistently established at one or more locations in the Chihuahuan and Sonoran Deserts. Consistently established genera are *Eragrostis*, *Sorghum*, *Panicum*, *Bouteloua*, *Cenchrus*, and *Leptochloa*. All are perennial, warm-season grasses, and two are natives. The most widely adapted species are Lehmann and Boer lovegrasses. Both are introductions from South Africa.

Elevation, precipitation, frost-free days, and season of precipitation are commonly used to select species for seeding rangelands, but data integration to determine the number of days when air temperature exceeds 21°C and soil moisture is available may be more useful. This parameter has not been sufficiently measured, but it appears to be related to plant survival. For example, it is assumed that Lehmann lovegrass requires mild winter temperature and summer and winter growth periods; however, the species germinates, persists, and naturally spreads within a single growing season at sites in the Chihuahuan Interior Plateau and where winter temperatures may be colder than those in southern New Mexico. Annual growth days may exceed 60 days during atypical years in southern New Mexico. In such years, Lehmann lovegrass is known to germinate, grow, and flourish, but the species fails to survive in typical growth years of 40 to 60 days. Whereas, in southeastern Arizona, where summer growth days may be as high as 35 and winter growth days 40 or more, the species thrives.

Seedbed preparation methods are difficult to compare among sites, and seeding success varies among treatments and sites. Generally, root plowing followed by pitting increases soil moisture and reduces runoff, but pit size may be beneficial or harmful depending on year, size, and soil type. However, no single seedbed treatment has been shown to be superior to any other at all locations and in all years.

FUTURE NEEDS IN RANGELAND SEEDING

The information obtained from past rangeland seeding provides a foundation upon which future studies can build. Our recommendations are that researchers--

1. Describe vegetation and soils sites before and after planting.

2. Measure daily precipitation, temperature, and humidity.

3. Compare new methods of seedbed preparation with a standard, such as root plowing or disking. All species should be compared with a standard and sown at known rates of pure live seed.

4. Gather data on density and aboveground production per unit area through time to indicate species or treatment longevity in relation to concurrent precipitation, humidity, and temperature data.

5. Systematically identify plant introduction numbers and collection sites.

6. Establish a data bank to make information from past studies available, reduce unnecessary duplication, and provide reliable information on adapted species.

Rangeland seeding sites are typically located above 1100 m, and seeding trials are usually weighted with palatable native and introduced grasses. Future research might be more useful if focused in the following areas:

1. Seeding Abandoned Farmland: Approximately 20 million ha of abandoned farmland are in the southwestern United States and northern Mexico (Brower *1981*; Sheets *1981*). A valuable forage base might be developed if such areas were seeded with range grasses and shrubs following final crop harvest and irrigated for 1 year (Barnes et al. *1973*, *1974*, *1975*, *1976*).

2. Allelopathy: Determine the effects of natural plant litter on seed germination and seedling growth. If natural plant litter adversely affects stand establishment (Knipe and Herbel *1966*; Hull and Muller *1977*; Fay and Drake *1977*; Bokhari *1978*; Cox et al. *1981*), the allelopathic effects should be tested under field conditions to determine their relative importance.

3. Litter Production: Emphasize coarse perennial bunchgrasses (Kemph et al. *1976*) that accumulate litter (Glendening *1944*). Fire might then be used to manipulate vegetation and grazing (Oefenger and Scifres *1977*).

4. Screening New Plant Materials: Develop quick physiological screening techniques to evaluate plant adaptability. Shrubs and grasses can be germinated and grown in a protected environment, hardened, and then transplanted in the field (Hodder *1970*; Springfield *1972*, *1973*; Lavin and Johnsen *1975*).

5. Determining Where Reseeding is Necessary: Before mechanical treatments and reseeding, establish exclosures and control shrubby plant competition and grazing. If forage production from native grass does not rapidly increase, reseeding will be necessary.

SUMMARY AND CONCLUSIONS

More than 300 species have been planted on 40 mechanically prepared seedbeds at 400 locations within the Chihuahuan and Sonoran Deserts. Eighty-three species have been listed as successful and recommended for rangeland use. Our results indicate that 14 species are sufficiently adapted to warrant general consideration. Eleven adapted species are introduced perennial grasses, two are native perennial grasses, and one is a native perennial shrub.

Seeded preparation methods were usually not compared, and not all have been tested at all sites. We were unable to find a seedbed method that generally

aided in plant establishment throughout the Chihuahuan and Sonoran Desert areas. Methods such as root plowing or combinations of root plowing and pitting for brush control and water conservation were most widely used.

Major climatic differences between the Chihuahuan and Sonoran Deserts are easily recognized, but minor climatic variation within deserts may not be recognized without specific site information. We separated planting sites into eight reference zones based on elevation, precipitation, season of precipitation, frost-free days, and annual growth days. Annual growth days--the number of days when air temperature is above 20°C and soil moisture is available for plant use--appears to be a useful classification for selecting adapted species.

Frequent drought and continual abuse by man has caused the deterioration of the semidesert grasslands in North America. The result is accelerated soil erosion, brush invasion, and reduced forage production. Revegetation is difficult and costly, but not impossible.

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